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A Frontier Approach to Canada-U.S. Multifactor Productivity Performance

by Kaïs Dachraoui and Tarek M. Harchaoui

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Aussi disponible en français

Table of Contents

Abstract

Much of the recent Canadian productivity debate has focused on the Canada-U.S. productivity growth gap but fewer efforts have been directed to tracing and quantifying its sources. This paper fills this gap by exploiting the frontier approach to productivity measurement. Using a nonparametric programming method, we construct a North American frontier for the business sector and for the manufacturing sector based on data from the two countries. Each sector or industry is compared to that frontier. How much closer a particular sector or industry of any country gets to the North American frontier is known as technical efficiency and results from 'catching up' to best-practice production technology; how much the North American frontier shifts at each sector's or industry's observed input mix is known as 'technical change' and results from the type of innovation that brings best-practice technology into the country. The combined effect of these two changes yields a frontier version of multifactor productivity growth that is derived from the Malmquist index of multifactor productivity growth.

The paper concludes that, whether at the level of the aggregated business sector or at the manufacturing sector level, Canada's productivity 'problem' during the 1988-2000 period, is mostly ascribed to the deterioration of its technical efficiency—or the extent to which firms are using production technology that places them behind the leaders. The results also suggest that Canada's productivity surge in the 1995-2000 period was mainly due to a recovery in its technical efficiency. We also find that, over the 1981-1997 period, the dispersion of the distribution of technical efficiency across North American manufacturing industries increased drastically.

Keywords: productivity, efficiency, technical change, Malmquist index.

Executive Summary

This paper explores an alternate experimental measure of multifactor productivity growth based on the production frontier, a method that benchmarks observed units (firms or industries) against an estimated best-practice production frontier. This estimated frontier specifies the maximum possible output that can be produced from different combinations of inputs, based on the observed input-output mixes of sampled industries or firms. Benchmarking each unit against such a frontier generates a relative measure of its efficiency compared to what is theoretically possible by following best practice. This measure is based on a distance from the estimated production frontier and ranges from zero (no output produced) to one (maximum output allowed by the technology on the frontier).

This paper employs a Malmquist index to calculate a measure of productivity change that takes into account both movements in the production frontier and how close firms are to that frontier. How much closer a particular sector or industry of any country gets to the North American frontier is known as technical efficiency and improvements in efficiency occur when firms 'catch up' to best-practice technology; how much the North American frontier shifts at each sector's or industry's observed input mix is known as 'technical change' and results from the introduction of 'innovations' that advance best-practice technology. Changes in the frontier arise because of innovations that lead to the adoption of best-practice technology in Canada. Changes that bring firms closer to the best-practice production frontier occur when advanced technologies are diffused from the leaders to the followers in an industry or from one industry to another.

The combined effect of these two changes yields a frontier version of multifactor productivity growth or the Malmquist index of multifactor productivity growth, defined in terms of output distance functions. Unlike the traditional indexes employed in productivity analysis, the Malmquist index has the property of making the distinction between efficiency change and technical change. This distinction is important as the technical change component reflects only the potential for technical change for a given industry. Any outward shift in the frontier may leave non-innovators behind, that is, their efficiency may fall when technical progress occurs. If technology improvements that are made by industry leaders diffuse only slowly to industry followers, inefficiency increases.

Using Canada-U.S. data for the business sector and its constituent manufacturing industries, the paper reaches the following conclusions:

1) At the aggregate business sector level, the U.S. set the technical efficiency frontier of the North American economy for the 1981-2000 period. The Canadian business sector was not far behind the North American efficiency frontier during the 1981-1987 period; but it subsequently fell behind until 1992 when it stood at only 90% of the U.S. efficiency. Canada's business sector technical efficiency trended up since 1993 and by the end of the 1990s it recovered much of the lost ground experienced between the late 1980s and the early 1990s. While the analysis does not establish whether the recovery of Canada's efficiency should be attributed to cyclical forces or to changes in the underlying trend, it indicates that the recent productivity revival is due to the improvement in Canada's technical efficiency.

2) Over the entire period, productivity growth in the aggregate business sector in Canada was behind that of the United States, primarily because of the deterioration in the technical efficiency in Canada. Thus the primary problem was the slower rate of diffusion of best-practice technology in Canada.

3) The manufacturing sector presents a similar story. In the manufacturing sector, the productivity growth gap in favour of the U.S. during the 1981-1997 period, much like its business sector counterpart, is attributable to Canada's efficiency degradation compared to the U.S. Both countries showed an almost identical pace of technical change over the same period (7.5% for Canada and 7.6% for the U.S.).

4) The North American manufacturing sector experienced a major shift in the distribution of technical efficiency. In 1982, all of the thirty eight manufacturing industries had efficiency levels higher than 0.70, (the level '1' means that the industry is technically efficient) compared to 17 industries in 1988 and only 6 industries in 1997. Out of these 17 industries in 1988, only 6 were Canadian, compared to 3 out of 7 in 1997. Two phenomena have emerged: First, there was a change in the nature of the skewness of the technical efficiency distribution over the years. Second, a large proportion of Canadian industries improved their efficiency during the mid-1990s. In 1997, for example, one out of two of the least technically efficient North American industries were Canadian. This is a sharp decline compared to 1988 when Canada had two industries out of three of the least technically efficient.

1. Introduction

The relative productivity performance of the Canadian and the U.S. economies remains an important area of inquiry among economists and policymakers. Interest in this topic has increased in view of the Canada-U.S. Free Trade Agreement and its implications for trade volume, living standards, and industrial development.

While the productivity gap between Canada and the U.S. has generally narrowed during the 1960s and the 1970s, recent evidence suggested that this convergence has stalled, triggering the so-called 'Canadian productivity debate'. Although much of the debate has focused on the existence of the Canada-U.S. productivity growth gap, there have been few attempts to trace this gap to its source. This paper exploits the frontier approach to productivity measurement in order to quantify the extent to which this gap arises from shifts in the production frontier (technical change) or whether it is caused by firms moving closer to the frontier (efficiency change). Technical change results from shifts in the production frontier and arises because of innovations that lead to the adoption of best-practice technology in Canada. Efficiency improvements occur when firms move closer to the best-practice production frontier. This is brought about by the diffusion of advanced technologies from the leaders to the followers in an industry or from one industry to another.[1]

To pursue our goal, we apply the Malmquist index and we decompose multifactor productivity growth into two components—changes in efficiency and shifts in technology over time. We use a technique developed by Färe *et al.* (1989) to construct a North American frontier based on data covering the Canadian and U.S. business sectors, the manufacturing sectors and its constituent industries. Each national sector or industry is compared to the corresponding North American frontier. How much closer a country sector or specific industry gets to the North American frontier is called 'catching up'; how much the sectoral or industry frontier shifts at each observed input mix is called 'technical change' or 'innovation'. The combination of these two changes yields a frontier version of multifactor productivity change.

The paper finds that Canada's 'productivity problem', which emerged during the second half of the eighties, is largely ascribed to the deterioration of its efficiency—Canada is getting farther away from the North American frontier. For example, during the 1981-1997 period, close to three-fifths of the productivity growth gap in favour of the U.S. was attributable to the decline of Canada's efficiency at 0.3% per year on average.

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1 The productivity group in the Micro-Economics Analysis Division produces a set of non-parametric multifactor productivity estimates that accord with international best practice as outlined by the OECD Productivity Manual (OECD 2001). However, in order to keep abreast of new developments and to provide quality control for the databases that are used to produce these estimates, the productivity group also experiments with alternate methods of measuring productivity. The estimates in this paper are derived from one such attempt to explore a new domain—one that tries to separate gains in productivity from shifts in the production frontier and from movements of firms that are off the frontier to points closer to the frontier. The estimates in this paper are experimental and will differ from the official estimates that are listed in Statistics Canada's CANSIM database.

Canada's efficiency problem exists across most major sectors. Canada's productivity growth gap in the manufacturing sector, at 0.7 percentage points, is almost entirely due to its more rapid efficiency deterioration compared to the U.S.

The remainder of the paper is organized as follows: Section II provides a brief introduction to the Malmquist productivity index. Section III discusses the data sources and provides a descriptive analysis of the data. Section IV discusses the application of this method to the data along with the results and their implication. A comparison of the results of the frontier analysis to the results obtained by the standard productivity estimation procedure is included in Section V. Concluding remarks are presented in Section VI. The Appendix provides more technical details on the frontier approach utilized in this paper.

II. Productivity Measurement: A Frontier Approach

In this section, we provide an intuitive introduction to the Malmquist index. A more formal presentation of the index, the distance measure from which it is constructed, and an explanation of how the productivity measures are calculated, are given in the Appendix.

Figure 1 illustrates the simple case where input x is used to produce one output y and the technology is characterized by constant returns to scale. The constant returns to scale technologies for period t, S^t, and period $t+1$, S^{t+1} are bounded by the x-axis and the rays from the origin. Observations $\left(x^t, y^t\right)$ belong to the technology of period t and similarly for observations of period $t+1$

Note that technical efficiency at time t and $t+1$ are respectively given by $\frac{OF}{OE}$ and $\frac{OC}{OA}$. Productivity growth P_o in our example is measured by

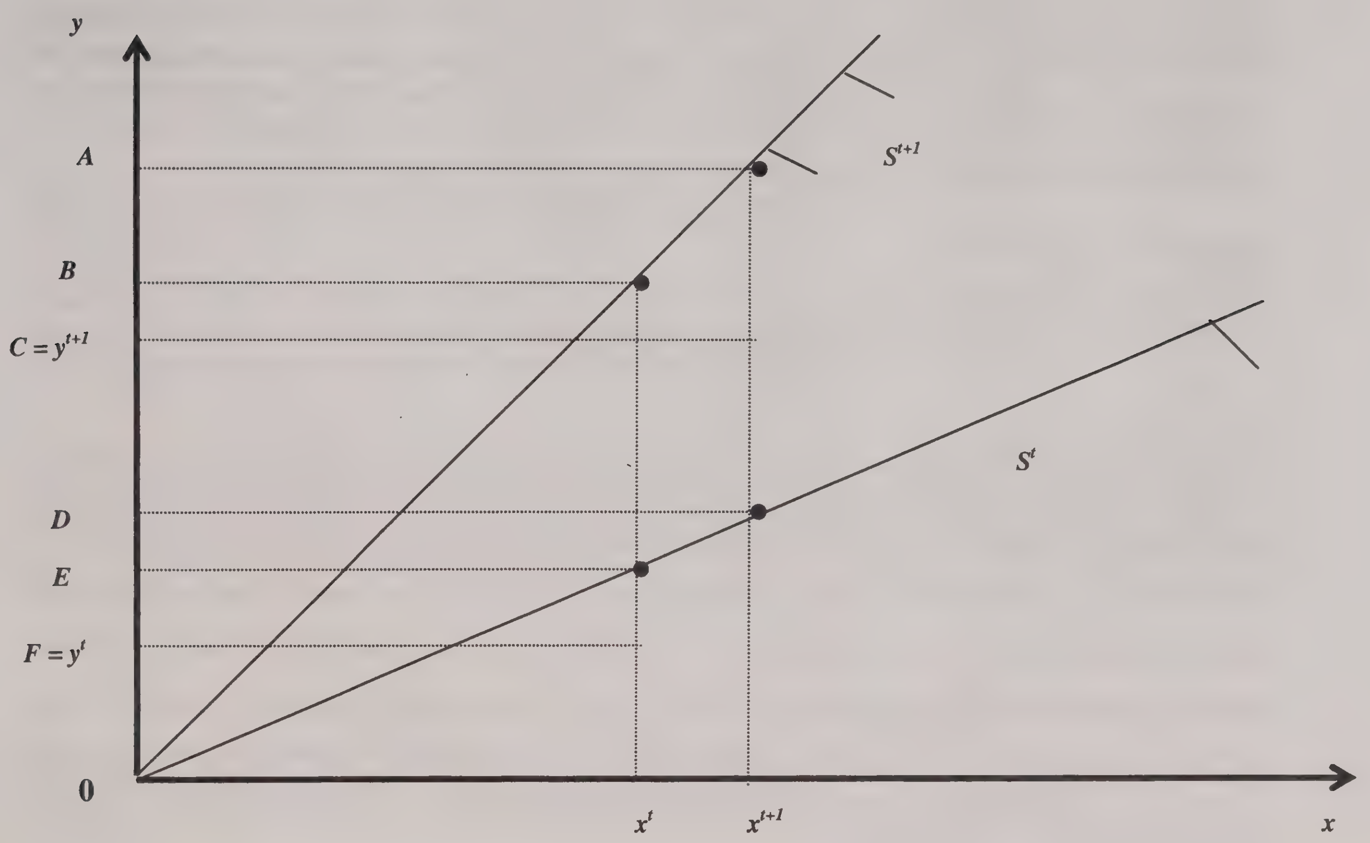
$$P_o = \left(\frac{\frac{OC}{OX_{t+1}}}{\frac{OF}{OX_t}} \right). \tag{1}$$

Now this expression can be rewritten as

$$P_o = \left(\frac{\frac{OC}{OA}}{\frac{OF}{OE}} \right) \left(\frac{\frac{OA}{OX_{t+1}}}{\frac{OE}{OX_t}} \right). \tag{2}$$

The first term in equation (2) is the ratio of the relative efficiency of production in the $t+1$ period to that in period t, while the second term is the ratio of productivity of frontier production in period 2 to productivity of frontier production in period t. Overall productivity P_o can increase either because efficiency improves or because the frontier shifts upwards.

Figure 1. Malmquist Multifactor Productivity Index



Productivity P_o in this example can also be written as

$$P_o = \left(\frac{\frac{OC}{OD}}{\frac{OF}{OE}}\right)\left(\frac{\frac{OD}{OX_{t+1}}}{\frac{OE}{OX_t}}\right) = \left(\frac{\frac{OC}{OD}}{\frac{OF}{OE}}\right) \text{since } \frac{OD}{OX_{t+1}} = \frac{OE}{OX_t}. \tag{3}$$

Alternately it can be written as

$$P_o = \left(\frac{\frac{OC}{OA}}{\frac{OF}{OB}}\right)\left(\frac{\frac{OA}{OX_{t+1}}}{\frac{OB}{OX_t}}\right) = \left(\frac{\frac{OC}{OA}}{\frac{OF}{OB}}\right) \text{since } \frac{OA}{OX_{t+1}} = \frac{OB}{OX_t}. \tag{4}$$

Using our example, the Malmquist index is the geometric mean of equation (3) and (4)

$$M_o = \left(\frac{\frac{OC}{OD}}{\frac{OF}{OE}}\right)^{\frac{1}{2}}\left(\frac{\frac{OC}{OA}}{\frac{OF}{OB}}\right)^{\frac{1}{2}}. \tag{5}$$

Equation (5) is the geometric average of two terms, each of which is the rate of change in technical efficiency. For example, the first term in (5) measures relative technical efficiency using the inputs applied at time $t+1$ and the production frontier of time t over the relative efficiency using inputs at time t and the same production frontier. As such, it captures efficiency changes that occur as the amount of inputs change, that is, whether production is getting closer or farther from the frontier (catching up effect). The second term is a similar measure but uses the production frontier at time $t+1$. The overall index is thus a geometric mean of two shifts in efficiency measured using the production technology of two different periods.

Equation (5) can be written as:

$$M_o = \left(\frac{\frac{OC}{OA}}{\frac{OF}{OE}} \right) \left(\frac{OA}{OD} \cdot \frac{OB}{OE} \right)^{\frac{1}{2}}. \tag{6}$$

The first term in (2) measures relative technical efficiency at time t and $t+1$ and captures efficiency changes that occur between the two time periods, that is, whether production is getting closer or farther from the frontier (catching up effect). The second term is the geometric mean of two ratios: $\frac{OA}{OD}$ that captures what potentially could have been produced using technology at time $t+1$ relative to what could have been produced using the technology at time t given the input of period $t+1$, $\frac{OB}{OE}$ is the same ratio, but is evaluated using the input of period t. The measure of technical change is thus a geometric mean of two shifts in technology at input levels x_t and x_{t+1}. The Malmquist index then jointly captures the shift in the production function and the increase in relative efficiency.

The Malmquist index and its components are calculated under the assumption of constant returns to scale technology. We would expect the technical efficiency component to capture the effects of technology diffusion. Fluctuations in productivity due to the variation in capacity utilisation and differences in the structure of each industry will also be reflected in changes in the efficiency component.

Improvements in productivity yield Malmquist index values greater than one hundred. Deterioration in performance over time is associated with a Malmquist index less than one hundred. The same interpretation applies to the values taken by the components of the overall multifactor productivity index. Improvements in the efficiency component yield index values greater than one hundred and are considered to be evidence of catching up to the frontier. Values of the technical change component greater than one hundred are considered to be evidence of technological progress. The component values may move in opposite directions. Thus, in situations where inefficiency exists, multifactor productivity growth is defined as the net effect of changes in efficiency and shifts in the production frontier, the latter being technical change.[2]

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[2] In the standard growth accounting and non-parametric index number approaches, such inefficiency is typically ignored.

It should be noted that when the distance measures are used with industry rather than firm level statistics, we are implicitly assuming that the factor proportions that set the frontier are feasible to every industry—that technology does not constrain an industry from being able to use the factor proportions found in another industry to achieve just as much real output. Then, our measure of efficiency change over time captures the extent to which resources are ultimately being reallocated towards those industries where factors use is most productive.

III. Data Sources and Descriptive Statistics

The model detailed in the previous section is estimated using Canadian and U.S. data for the business sector over the 1981-2000 period and for the manufacturing sector and its constituent 19 two-digit manufacturing industries over the period 1981 to 1997.

The data on real output, capital and labour inputs for the business sector, the manufacturing sector and its constituent manufacturing industries are from Statistics Canada and the U.S. Bureau of Labor Statistics (BLS) KLEMS databases, with one exception. Manufacturing real output estimates are from the U.S. Bureau of Economic Analysis, which produces estimates of real value added, comparable to their Canadian counterpart. A brief description of the data set is in order.[3]

Real Output: Real gross domestic product is the basis of the output measure that is used here for productivity estimates of the business sector. This output measure is based on and is consistent with the Income and Expenditures Accounts (IEA) and the National Income and Product Accounts (NIPA) prepared, respectively by Statistics Canada and the U.S. Bureau of Economic Analysis.

Real business sector output is an annual-weighted (Fisher) index. It is constructed from the gross domestic product (GDP) excluding the following components: General government, non-profit institutions and the rental value of owner-occupied dwellings. These same exclusions are made when calculating current dollar output and inputs (in current and constant prices) for the sector.

For the manufacturing sector and its constituent industries, the study makes use of the concept of real value added (gross product originating in the U.S.), defined as gross output minus intersectoral transactions or intermediate inputs (goods and service inputs purchased from other domestic industries and foreign sources).[4] Value added represents, therefore, the value that is added, by the application of capital and labour to intermediate inputs in converting those inputs to finished products.[5]

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3 Output and inputs were aggregated up from detailed components and then the Malmquist methodology was applied at the level of one output and two combined inputs.

4 Gross output is equal to sales, plus inventory change.

5 The U.S. aggregate output based on the notion of gross output originating (which is analogous to value added) tends to overestimate the business sector's GDP growth in comparison to final demand GDP.

Labour Input: Both Canada and the U.S. make use of the same concept of labour input in their business sector estimates of multifactor productivity. Canada makes use of household survey data to disaggregate total hours into hours worked by different types of workers classified by demographic variables such as age and education. Labour input is calculated as a weighted sum of hours worked by different types of workers, and the hours worked of the different categories are weighted by their relative wage rates. This is done to take into account differences in labour composition.

At the level of the business sector, the BLS breaks the hours worked down into three categories—educational attainment, work experience, and gender. Statistical regression techniques are used to remove the impact of other worker characteristics such as marital status on average wage rates in each of these three groups. The BLS then uses predicted wage rates for each of the categories. Canada uses educational attainment, age and worker type for its groupings and uses average wage rates in each of the categories as weights without correcting for other worker characteristics.[6]

In contrast to the practice followed for the business sector, U.S. labour input for manufacturing is measured as the sum of hours at work of all persons. Therefore, in order to provide cross-country comparability in this study, Canadian labour input estimates both for the business sector as a whole and for the manufacturing sector were brought to the lowest common denominator, which is the straight sum of hours worked. Hence, in this study hours for both Canada and the U.S. are directly aggregated across all worker groups and the resulting growth rates that are calculated from this sum do not include the effects of changing labour composition.

Capital Input: The capital input for the multifactor productivity measures in both Canada and the U.S. is computed in accordance with a service flow concept for physical capital assets—machinery and equipment, structures, inventories, and land. Capital inputs for major sectors are determined in three main steps: 1) a detailed array of capital stocks is developed for various asset types in different industries; 2) asset-type capital stocks are aggregated for each industry to measure capital input for the industry; and 3) industry capital inputs are aggregated to measure sectoral level capital input.

The Canadian asset detail consists of 16 types of machinery of equipment (28 for the U.S.), 6 types of non-residential structures (22 for the U.S.), 4 types of residential structures[7] (9 for the U.S.), 3 types of inventories (by stage of processing), and land.

For each industry, Statistics Canada' procedures are applied to 122 industries (57 for the U.S.) in the business sector corresponding, approximately, to the 3-digit 1980 SIC level (2-digit 1987 SIC for the U.S.). These measures of capital stocks are aggregated using a Fisher (Törnqvist for the U.S.) chain index procedure. The weight for each asset type is based on the share of property income estimated to be accruing to that asset type in each industry averaged over 2 years. Property income in each industry is allocated to asset types by employing estimates of the

6 Not taking worker characteristics into account has little effect on the estimates (See Baldwin and Harchaoui, 2001, chapter 3)

7 Owner-occupied housing is excluded for both countries.

'implicit rental prices' of each asset type. Because some asset types tend to deteriorate much more quickly than others and because of tax rules that are specific to asset types, the economic cost (rental price) of employing a dollar's worth of stock varies substantially by asset type.

Table 1a. Average Annual Growth Rates of Output and Inputs, 1981-1997: Business Sector (1981=100)

	Real GDP		Capital Services		Hours	
	Canada	U.S.	Canada	U.S.	Canada	U.S.
1981	100.0	100.0	100.0	100.0	100.0	100.0
1982	95.1	97.2	102.5	104.1	94.9	97.3
1983	98.0	102.5	104.9	107.4	94.9	99.1
1984	105.5	111.6	107.3	112.6	97.9	105.0
1985	110.9	116.4	111.2	117.9	102.1	107.2
1986	113.7	120.7	115.3	123.0	105.5	107.8
1987	119.5	125.1	120.9	127.1	109.8	111.1
1988	125.5	130.5	127.3	130.9	114.6	114.5
1989	128.3	135.1	133.9	134.9	117.3	117.3
1990	126.6	137.0	138.4	138.5	116.6	117.4
1991	120.9	135.4	141.7	141.7	111.7	114.6
1992	121.4	140.5	143.6	144.6	109.6	114.6
1993	125.2	145.1	145.0	148.3	111.3	117.6
1994	134.0	152.1	148.6	152.9	115.0	121.7
1995	139.3	157.0	152.7	158.7	116.9	124.8
1996	142.7	163.9	157.4	165.3	119.8	126.7
1997	151.2	172.5	165.1	173.4	123.8	130.4
1998	158.3	181.1	173.0	184.1	126.9	133.4
1999	167.8	189.7	180.4	195.0	131.3	136.1
2000	176.6	198.4	187.6	206.6	136.1	137.6
1981-2000	**3.0**	**3.7**	**3.4**	**3.9**	**1.6**	**1.7**
1981-1997	**2.6**	**3.5**	**3.2**	**3.5**	**1.3**	**1.7**

At the sector level, aggregate capital input is obtained by a fisher chained index for Canada and a Törnqvist index for the U.S. by aggregating each industry's capital input using each industry's two-period average share of total capital income as weights.

In Tables 1a and 1b, we provide the average annual growth rates of real output and real inputs for the business sector over the 1981-2000 period, the manufacturing sector and its constituent industries for the period 1981-1997.

Over the 1981-2000 period, the U.S. business sector's real GDP grew at a faster pace than its Canadian counterpart (3.7% for the U.S. vs. 3.0% for Canada), while capital deepening (as measured by the growth of the ratio of capital services to hours) in Canada grew at a slower pace than in the U.S. rate (1.8 percent vs. 2.2 percent, respectively for Canada and the U.S.).

The data for the manufacturing sector cover only the period 1981-1997. Over this period, the gap in output growth was slightly greater for the business sector (2.6% for Canada compared with 3.5% in the U.S.) than it was for the entire 1981-2000 period. The U.S. also has a faster growth

rate in the manufacturing sector (3.8% in the U.S. vs. 3.1% for Canada) and a more rapid increase of capital deepening (2.6% in the U.S. vs. 2.3% for Canada).

Table 1b. Average Annual Growth Rates of Output and Inputs, 1981-1997: Manufacturing Sector

Industry	Canada			U.S.		
	Real GDP	Capital Services	Hours	Real GDP	Capital Services	Hours
Manufacturing Sector	**3.1**	**2.5**	**0.2**	**3.8**	**2.5**	**-0.1**
Food and kindred products	1.2	0.8	-0.2	-0.6	1.8	0.3
Tobacco	-1.8	-1.9	-4.0	-4.3	1.7	-3.1
Textile mill products	0.6	0.0	-1.1	1.1	0.8	-1.4
Apparel and related products	0.2	0.3	-1.4	1.8	1.5	-2.1
Lumber and wood products	0.5	1.0	1.4	4.2	-0.3	1.5
Furniture and fixtures	2.1	1.6	2.4	3.5	2.4	1.2
Paper and allied products	1.8	1.2	-0.8	0.3	2.4	0.4
Printing and publishing	0.1	2.7	1.5	2.9	4.4	1.7
Chemical and allied products	3.6	0.4	0.1	1.8	2.6	-0.2
Petroleum refining	0.8	-0.01	-0.03	8.1	0.9	-2.5
Rubber and misc. plastic products	5.2	4.5	3.0	1.2	3.6	1.9
Leather and leather products	-4.1	-1.9	-4.5	1.1	-1.2	-5.6
Stone, clay, glass and concrete	0.6	-1.9	-0.1	2.3	-0.4	0.1
Primary metals	3.8	-0.6	-1.3	-0.4	-0.8	-1.9
Fabricated metal	1.7	1.5	1.7	6.0	1.5	0.1
Industrial and commercial machinery and computer equipment	8.2	1.6	1.2	10.5	3.9	-0.3
Electronic and other electrical equipment except computers	1.9	4.5	-0.5	4.1	5.7	0.1
Transportation equipment	4.6	6.8	2.4	0.7	1.7	0.5
Instruments and miscellaneous manufacturing	4.1	3.0	1.2	3.4	3.2	-0.5

The variation in the U.S. annual rates of growth of output by industry as shown in Table 1b is significantly higher than in Canada. Some industries experienced impressive gains in output. The highest growth rates were found in the industrial and commercial machinery and computer equipment in Canada (8.2%) and in the industrial and commercial machinery and computer equipment in the U.S. (10.5%). Instruments and miscellaneous manufacturing experienced relatively high growth in the two countries as well—4.1% in Canada and 3.4% in the United States. But after that, the list of the fastest growing industries generally differs in the two countries: rubber (5.2%), transportation (4.6%) and chemicals (3.6%) in Canada and petroleum refining (8.1%), electronics (4.1%), lumber (4.2%) and furniture (3.5%) for the U.S.

Output grew at a moderate pace, ranging from 1.7% to 2.1% annually, in fabricated metals, paper and allied products and electronic and other electrical equipment and furniture and fixtures in

Canada (apparel and related products, chemical and allied products, stone, clay, glass and concrete, and printing and publishing in the U.S., ranging from 1.8% to 2.9%).

In contrast, output growth was rather modest in food and kindred products (1.2%), petroleum refining (0.8%) and lumber and wood products (0.5%) in Canada and in rubber and miscellaneous plastic products (1.2%) and transportation equipment (0.7%) in the U.S. Declines in output occurred in leather and leather products and tobacco in Canada and food products and tobacco in the U.S.

IV. Methodology and Analysis of the Results

1. *Implementation of the Frontier Technique to Canada-U.S. Data*

The substantial diversity in the growth of output and inputs for sectors and across the industries provides a rich body of data from which we construct a best-practice North American frontier. The North-American frontier was implemented differently for the business sector and for the manufacturing sector. The business sector of each country is benchmarked against a frontier that is estimated using a single period's data on the business sector's output and inputs for both Canada and the U.S.

For the manufacturing sector, two different but complementary approaches were used.

> First, data for each set of matched Canadian and U.S. manufacturing industries are used to build an overall North American manufacturing frontier each year. This is done by first constructing the individual frontier for all pairs of manufacturing industries (that is, lumber in Canada is compared to lumber in the U.S., steel against steel, etc.). These results are then aggregated to construct the estimates for the manufacturing sector of Canada and the U.S. The results derived from this approach are reported in Section 2.2.
>
> Second, we also applied a pooled approach to the frontier productivity measurement in the manufacturing sector. Each manufacturing industry of a particular country in each period was benchmarked against the production frontier defined over the entire sample of the North American manufacturing industries for the same time period (that is, lumber is compared to all other industries in establishing the frontier). While this approach maximizes the sample of observations used in any year and so may lead to more robust results, it has the disadvantage of assuming that all manufacturing industries share the same technology in each period. The results of this technique are presented in Section 2.3.

It should be noted that the various approaches all include, to varying degrees, the assumption that Canada can adapt to the production technology used in the United States. At the aggregate level, the frontier technique implicitly assumes that the business sector can aspire to the same input-output combinations as the U.S. business sector, despite differences in industrial structure. The first technique that is used to derive the results for the manufacturing sector is less affected by

this assumption, because it uses individual industry pair-wise comparisons across the two countries. But it should be recognized that these comparisons are only done at the 2-digit level and there may be considerable differences in composition within industries at this aggregation level. The second of the two techniques used in the manufacturing sector that compares a particular manufacturing industry to all other manufacturing industries explicitly assumes that any industry can be expected to move toward the results of the 'best' industry, no matter what the latter may be.

At first glance, this assumption is restrictive. Lumber cannot be produced within the confines of a petroleum refinery. But we are examining industries at a high level of aggregation. At this level, it is appropriate to examine how aggregate amounts of capital and labour are transformed into output and whether one industry is more efficient in doing so than another. It is, of course, true that the aggregates will be affected by industrial structure. But industrial structure affects averages, and it is a relevant factor in determining the efficiency of an economy to many observers. Although the effects of industrial structure might be purged from the analysis, that would be throwing out an important cause of differences.

2. Analysis of the Results

2.1. Business Sector

The average values of the index and its components over the 1981-2000 period and different sub-periods are presented in Table 2. If the value of the Malmquist index in the subsequent tables or any of its components is less than one hundred, this denotes a deterioration in performance. Values higher than one hundred denote an improvement in performance. It is important to emphasize that these indicators capture performance relative to the best practice in the sample, where the best practice refers to the grand frontier across Canada and the U.S.

Looking at the bottom of Table 2, it can be seen that the Malmquist multifactor productivity for the Canadian business sector as a whole increased on average by 0.6 percent over the 1981-2000 period (0.88 percent for the U.S.).

Close to three-fifths of this 0.28 percentage point productivity growth gap in favour of the U.S. is attributable to a deterioration of Canadian technical efficiency compared to the U.S.—at an average annual rate of 0.16% per year over the 1981-2000 period. The remainder is due to a more rapid U.S. technical change (0.88% for the U.S. compared to 0.76% for Canada).

The value attached to the business sector's technical efficiency index reveals that the U.S. set the frontier of the North American business sector for the entire 1981-2000 period. Canada's business sector jointly set the efficiency frontier during the 1981-1987 period along with the U.S. Canada fell continuously behind the U.S. until 1992 when its technical efficiency stood at 90% of its U.S. counterpart. The technical efficiency of Canada's business sector trended up after 1993. By the end of the 1990s, it had recovered most of the lost ground experienced between the late 1980s and the early 1990s. In 2000, for the first time in more than a decade, Canada almost entirely recovered its 1988 technical efficiency performance (97.1%), but still remained below

the U.S., albeit by a small margin. While the analysis does not establish whether the recovery of Canada's efficiency should be attributed to cyclical forces or to changes in the underlying trend, it simply indicates that the recent productivity revival is due to an improvement in Canada's technical efficiency.

Table 2. Malmquist Multifactor Productivity Index and Its Components, 1981-2000: Business Sector

	Multifactor Productivity		Technical Change		Efficiency	
	Canada	**U.S.**	**Canada**	**U.S.**	**Canada**	**U.S.**
1981	100.0	100.0	100.0	100.0	100.0	100.0
1982	96.7	96.6	96.7	96.6	100.0	100.0
1983	99.5	99.2	99.6	99.2	99.9	100.0
1984	103.9	103.0	103.9	103.0	100.0	100.0
1985	104.9	103.6	104.9	103.7	100.0	99.9
1986	104.0	105.1	104.0	105.2	100.0	100.0
1987	104.2	105.7	104.2	105.7	100.0	100.0
1988	104.0	107.0	105.1	107.1	98.9	100.0
1989	101.1	107.8	105.6	107.8	95.6	100.0
1990	98.3	107.9	105.8	107.9	93.1	100.0
1991	96.2	106.7	104.9	106.7	91.8	100.0
1992	98.4	109.6	108.9	109.6	90.4	100.0
1993	100.0	110.4	109.5	110.4	91.2	100.0
1994	103.6	112.0	111.0	112.0	93.3	100.0
1995	105.9	112.1	111.8	112.1	94.8	100.0
1996	105.7	113.8	112.1	113.8	94.3	100.0
1997	107.8	115.2	113.1	115.2	95.3	100.0
1998	108.9	116.1	113.6	116.1	95.9	100.0
1999	110.8	116.9	114.6	116.9	96.7	100.0
2000	112.1	118.2	115.5	118.2	97.1	100.0
1981-2000	**0.60**	**0.88**	**0.76**	**0.88**	**-0.16**	**0.00**
1981-1988	**0.56**	**0.98**	**0.72**	**0.98**	**-0.16**	**0.00**
1988-2000	**0.63**	**0.83**	**0.78**	**0.83**	**-0.15**	**0.00**
1988-1997	**0.41**	**0.82**	**0.82**	**0.82**	**-0.41**	**0.00**
1981-1997	**0.47**	**0.89**	**0.77**	**0.89**	**-0.30**	**0.00**

There are some differences in productivity performance in the two decades. Canada's business sector productivity growth gap during 1988-2000 was 0.2 percentage points, only half of that during 1981-1988 (0.42 percentage points). This is primarily the result of a lower gap in the technical change component (a decline from 0.26 percentage points to 0.05 percentage points).

2.2 *Manufacturing Sector*

We have explored the sources of Canada-U.S. multifactor productivity growth at the business sector level for the 1981-1997 period. It was demonstrated that the productivity growth gap in favour of the U.S. (0.42 percentage points) was largely attributable to a decline in Canadian efficiency.

We now turn our attention to industry data to trace aggregate multifactor productivity growth and its components to their sources in manufacturing industries. As was the case for the analysis of the business sectors of Canada and the U.S., individual manufacturing industries are benchmarked against a frontier based on a single-period pair of similar North American manufacturing industries. The remainder of this section summarizes our methodology and discusses the results.

Table 3.1: Malmquist Multifactor Productivity Index and Its Components, Manufacturing Sector: 1981-1997

	Multifactor Productivity Change		**Technical Change**		**Efficiency Change**	
	Canada	**U.S.**	**Canada**	**U.S.**	**Canada**	**U.S.**
Food and kindred products	100.7	97.0	106.8	107.0	94.3	90.7
Tobacco	102.1	98.0	108.3	110.0	94.3	89.0
Textile mill products	100.9	101.2	106.6	107.2	94.6	94.4
Apparel and related products	100.8	101.6	107.3	107.5	94.0	94.5
Lumber and wood products	99.5	104.1	106.5	106.3	93.5	98.0
Furniture and fixtures	100.1	101.3	106.1	106.9	94.4	94.7
Paper and allied products	102.0	98.5	107.6	106.9	94.7	92.1
Printing and publishing	97.4	99.2	106.4	106.9	91.6	92.8
Chemical and allied products	102.9	99.6	106.1	107.1	96.9	92.9
Petroleum refining	107.5	107.9	109.5	108.4	98.2	99.6
Rubber and misc. plastic products	101.9	97.8	107.6	106.9	94.7	91.5
Leather and leather products	100.3	106.2	108.7	109.6	92.3	96.9
Stone, clay, glass and concrete	102.5	102.4	106.4	106.3	96.3	96.2
Primary metals	105.5	101.0	107.5	107.9	98.1	93.7
Fabricated metal	100.3	104.9	106.6	107.2	94.0	97.9
Industrial and commercial machinery and computer equipment	108.7	109.5	107.4	109.4	101.3	100.0
Electronic and other electrical equipment except computers	102.5	102.5	109.8	109.6	93.4	93.5
Transportation equipment	101.9	99.1	109.4	106.8	93.1	92.8
Instruments and miscellaneous manufacturing	101.6	103.0	107.2	108.9	94.7	94.5
Manufacturing Sector (Average Annual Growth Rate in Percentage)	**2.0**	**2.7**	**7.5**	**7.6**	**-5.0**	**-4.5**

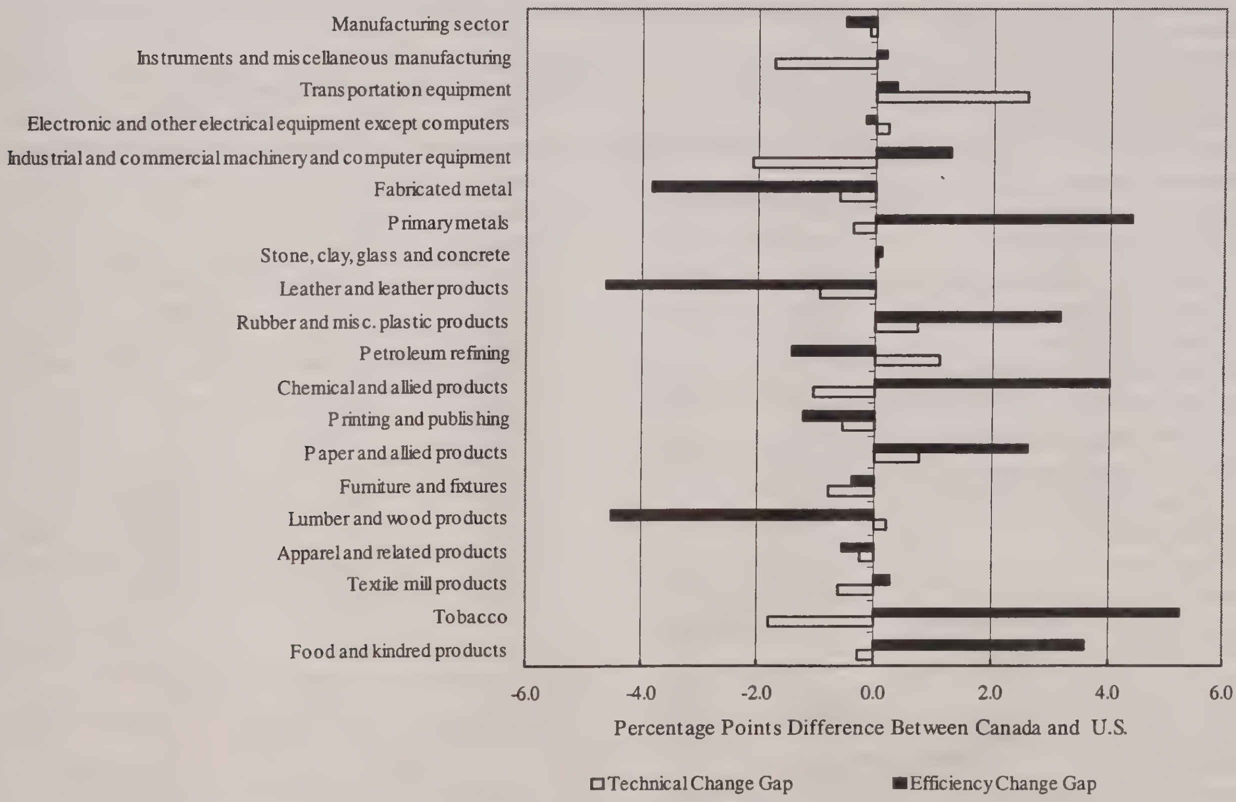
For the manufacturing sector, the results from the bottom of Table 3.1 indicate that Canada's productivity increased during the 1981-1997 period at an average annual growth rate of 2.0%, compared to 2.7% for its U.S. counterpart. This 0.7 percentage points gap is higher than the 0.42 percentage points observed for the business sector during the same period.

The gap in manufacturing productivity growth in favour of the U.S. during the 1981-1997 period, much like its business-sector counterpart, is attributable to the deterioration in Canada's efficiency. In contrast, both countries showed an almost identical pace of technical change over the same period (7.5% for Canada and 7.6% for the U.S.).

Productivity change is dominated by technical progress over the whole time period for the majority of industries in both countries. However, in almost all instances, technical change was accompanied by an opposite change in technical efficiency. This observation indicates that the concepts of technical change and efficiency change are not always positively related. This is because calculated measures of the technical change component reflect only the potential for technical change for a given industry. An outward shift in the frontier may leave non-innovators behind, i.e., their efficiency may fall when technical progress occurs. If technology improvements that are made by industry leaders diffuse only slowly to industry followers, the inefficiency of the latter increases. This finding suggests the need to distinguish technical or frontier change from the change in the extent to which firms approach the production frontier.

While technical change on average increased at about the same pace during the 1981-1997 period in both countries, there is a wide variation across industries (Figure 2). In transportation, petroleum refining, rubber and paper, Canada had an advantage over the United States. The opposite is the case for the rest of the industries, but the differences are small and along with the above mentioned industries where Canada had an advantage, average out to zero. On the other hand, Canada has an advantage in technical efficiency in primary metals, rubber, chemicals, paper, tobacco, and food products. But these advantages are more than offset by fabricated metals, leather, and lumber. The latter two industries actually experienced negative growth.

Figure 2. Gap in Technical Efficiency and Technical Change Between Canada and U.S. Manufacturing Industries, 1981-1997



Note: A negative sign indicates that the gap is in favour of the U.S.

Table 3.2: Malmquist Multifactor Productivity Index and Its Components, Manufacturing

	Multifactor Productivity Change		Technical Change		Efficiency Change	
	Canada	U.S.	Canada	U.S.	Canada	U.S.
			1981-1988			
Food and kindred products	101.6	101.2	108.2	108.4	93.9	93.4
Tobacco	103.9	90.4	110.3	110.8	94.2	81.6
Textile mill products	102.4	103.7	107.9	108.4	94.8	95.7
Apparel and related products	99.8	102.3	108.5	108.9	92.0	93.9
Lumber and wood products	102.3	107.9	108.1	107.9	94.7	100.0
Furniture and fixtures	98.7	101.0	107.2	108.0	92.1	93.4
Paper and allied products	100.2	102.1	108.4	108.1	92.5	94.5
Printing and publishing	100.0	97.8	107.6	108.3	93.0	90.4
Chemical and allied products	105.7	105.1	107.3	108.8	98.5	96.7
Petroleum refining	109.4	110.3	111.1	110.3	98.6	100.0
Rubber and misc. plastic products	101.5	103.1	109.1	107.9	93.0	95.5
Leather and leather products	101.1	103.6	109.5	110.7	92.3	93.5
Stone, clay, glass and concrete	105.7	103.6	108.0	107.6	97.9	96.2
Primary metals	104.3	99.8	108.7	110.5	95.9	90.3
Fabricated metal	101.4	104.5	108.1	108.9	93.8	96.0
Industrial and commercial machinery and computer equipment	104.9	107.3	110.1	110.4	95.3	97.2
Electronic and other electrical equipment except computers	101.0	105.2	110.9	110.1	91.1	95.6
Transportation equipment	101.4	105.1	108.9	108.2	93.1	97.1
Instruments and miscellaneous manufacturing	105.0	104.8	109.0	109.8	96.3	95.4
Manufacturing Sector (Average Annual Growth Rate (%))	**2.6**	**3.8**	**8.6**	**9.0**	**-5.4**	**-4.7**
			1988-1997			
Food and kindred products	100.0	93.7	105.5	105.9	94.7	88.5
Tobacco	101.3	103.8	106.8	109.4	94.9	94.9
Textile mill products	99.4	99.8	105.3	106.1	94.4	94.0
Apparel and related products	100.5	101.3	106.1	106.4	94.7	95.2
Lumber and wood products	97.5	101.2	104.8	104.6	93.0	96.8
Furniture and fixtures	101.1	101.4	105.0	105.8	96.2	95.9
Paper and allied products	102.0	96.2	106.9	105.8	95.4	90.9
Printing and publishing	95.8	99.8	105.2	105.8	91.1	94.3
Chemical and allied products	101.4	96.3	104.9	105.9	96.7	91.0
Petroleum refining	106.6	106.3	108.3	107.0	98.4	99.4
Rubber and misc. plastic products	101.7	94.5	106.5	105.9	95.5	89.2
Leather and leather products	99.4	108.0	108.0	108.7	92.1	99.3
Stone, clay, glass and concrete	100.1	101.8	104.7	105.0	95.5	96.9
Primary metals	105.5	102.4	106.5	105.9	99.0	96.7
Fabricated metal	99.8	106.5	105.3	105.9	94.8	100.6
Industrial and commercial machinery and computer equipment	109.8	110.8	106.1	108.7	103.5	101.9
Electronic and other electrical equipment except computers	103.0	100.8	109.0	109.1	94.5	92.4
Transportation equipment	103.2	95.7	109.5	105.5	94.2	90.7
Instruments and miscellaneous manufacturing	101.7	102.3	105.9	108.2	96.0	94.6
Manufacturing Sector (Average Annual Growth Rate (%))	**1.5**	**1.8**	**6.7**	**6.5**	**-4.7**	**-4.4**

2.3 Robustness of the Results and Extension of the Analysis

Given that the methodology used above relies on a pair of observations for each time period for the business sector and for the manufacturing industries, it is important to assess the robustness of the results using the pooled approach of measuring the frontier. This approach uses all manufacturing industries of both Canada and U.S. in each time period to construct the benchmark frontier. Both approaches yield consistent results for the whole manufacturing sector and its constituent industries. Under the pooled approach, the productivity growth gap in favour of the U.S. in manufacturing is lower (0.5 percentage points compared with 0.7 percent points under the approach used above) and it is still driven by the Canadian decline in technical efficiency. Although there are some differences in terms of order of magnitudes between the two approaches at the industry level, the results are consistent, as evidenced by a high rank correlation (0.89).

We can further exploit the pooling approach to highlight some interesting issues at the industry level for the North American manufacturing sector. For both Canada and the U.S., efficiency declined (albeit more so for Canada than the U.S.) during each of the sub-periods 1981-1988 and 1988-1997 (see Table 3.2). This suggests that most of the industries were getting further away from the North American frontier established by the industries reported in Table 4. It is also important to note that since the mid-1990s, there was a major change in the nature of the industries that established the North American frontier. Between 1981 and 1995, the frontier was essentially established by Canadian and U.S. industries that had close ties with the primary sector, replaced thereafter by the information technology producing industries.

Table 4. Canadian and U.S. Industries that Set the North American Efficiency Frontier of the Manufacturing Sector

	Canada	U.S.
1982	-	Transportation equipment
1983	Lumber and wood products, Transportation equipment	Petroleum refining
1984	Primary metals, Transportation equipment	Transportation equipment, Petroleum refining
1985	Lumber and wood products	Petroleum refining
1986	Lumber and wood products, Primary metals	Lumber and wood products
1987	-	Lumber and wood products, Petroleum refining
1988	-	Lumber and wood products, Petroleum refining
1989	Petroleum refining	Lumber and wood products, Petroleum refining
1990	Petroleum refining	Petroleum refining
1991	Petroleum refining	Petroleum refining
1992	Petroleum refining	Petroleum refining
1993	Primary metals	Petroleum refining
1994	Industrial and commercial machinery and computer equipment	Petroleum refining
1995	Industrial and commercial machinery and computer equipment	Industrial and commercial machinery and computer equipment
1996	Industrial and commercial machinery and computer equipment	Industrial and commercial machinery and computer equipment
1997	Industrial and commercial machinery and computer equipment	Industrial and commercial machinery and computer equipment

An equally important finding is the significant change both in the distribution of technical efficiency within the North American sector and in its dispersion. Figures 3 to 5 show a histogram of the level of technical efficiency for the 38 industries in 1982, 1988 and 1997. In 1982, all of the manufacturing industries had an efficiency level higher than 0.70, compared to 17 industries in 1988 (or 45% of all manufacturing industries) and only 7 industries (or 18%) in 1997. Out of these 17 industries in 1988, only 6 were Canadian (35%), compared to 3 out of 7 (43%) in 1997.

We draw two conclusions: First, there is a change in the nature of the skewness of the technical efficiency distribution over the years as evidenced by the change in the median technical efficiency level from 0.86 in 1982 to 0.68 in 1988 and then to 0.40 in 1997. Second, a large proportion of Canadian industries improved their efficiency during the mid-1990s. In 1997, for example, one out of two of the least technically efficient North American industries were Canadian, a sharp decline compared to 1988 when two out of the three most inefficient industries were Canadian. Nevertheless, this was still high in comparison to the early 1980s.

Figure 3. The Distribution of Technical Efficiency Levels Within the North American Manufacturing Sector, 1982

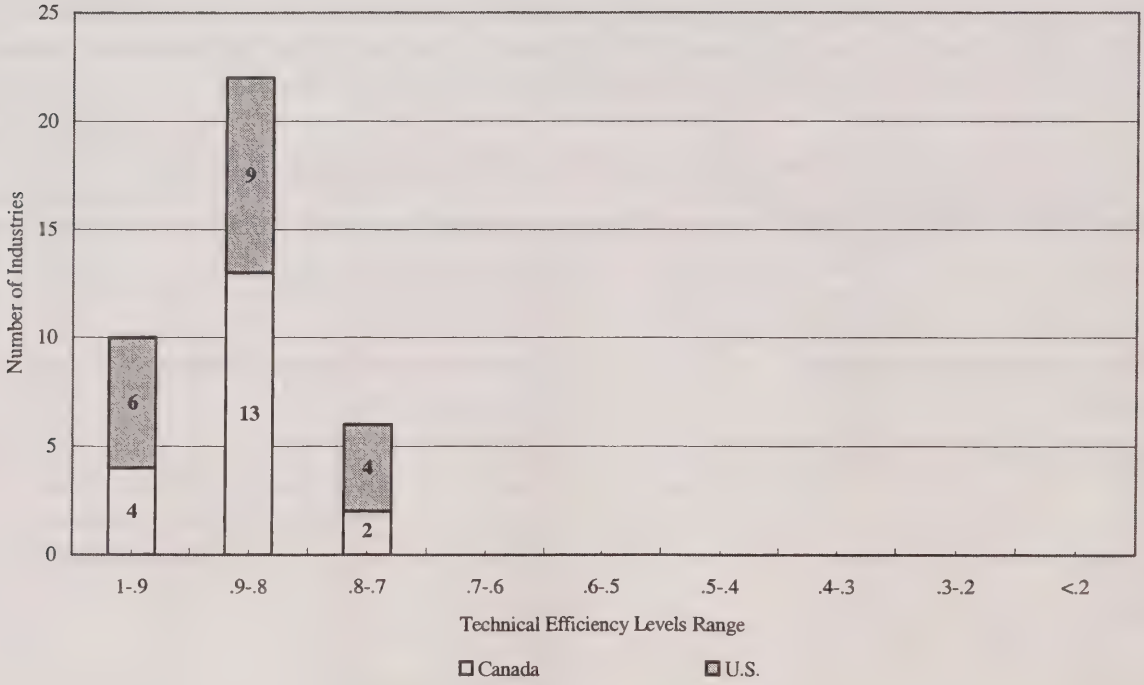


Figure 4. The Distribution of Technical Efficiency Levels Within the North American Manufacturing Sector, 1988

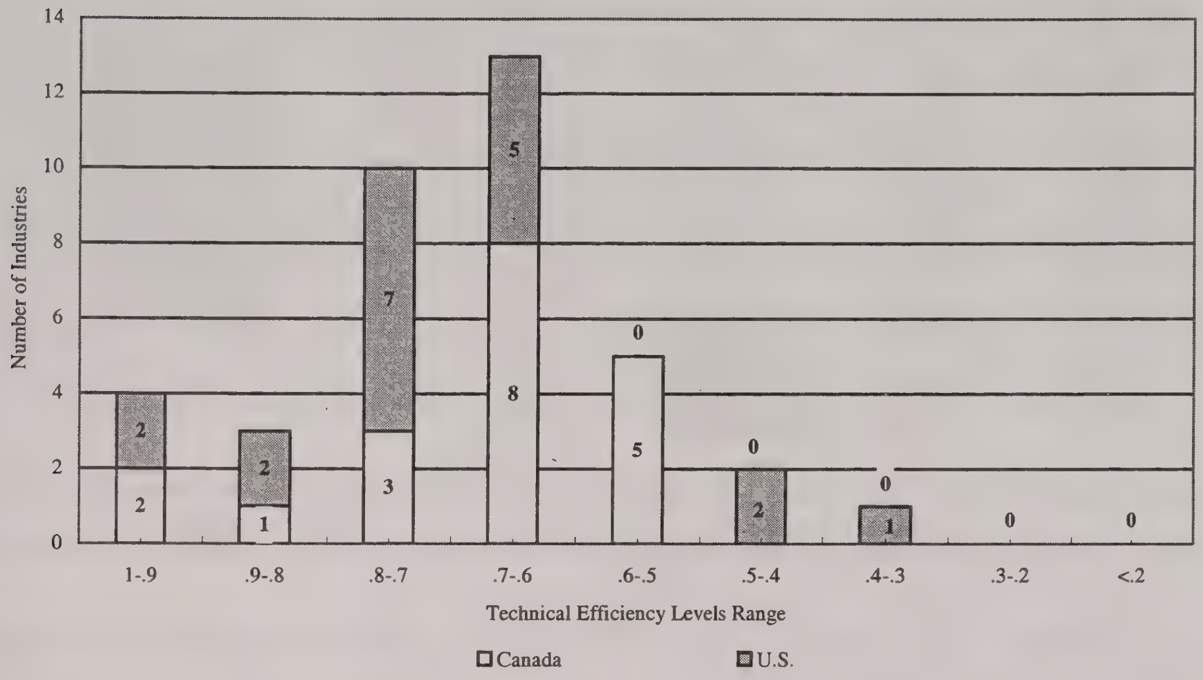


Figure 5. The Distribution of Technical Efficiency Levels Within the North American Manufacturing Sector, 1997

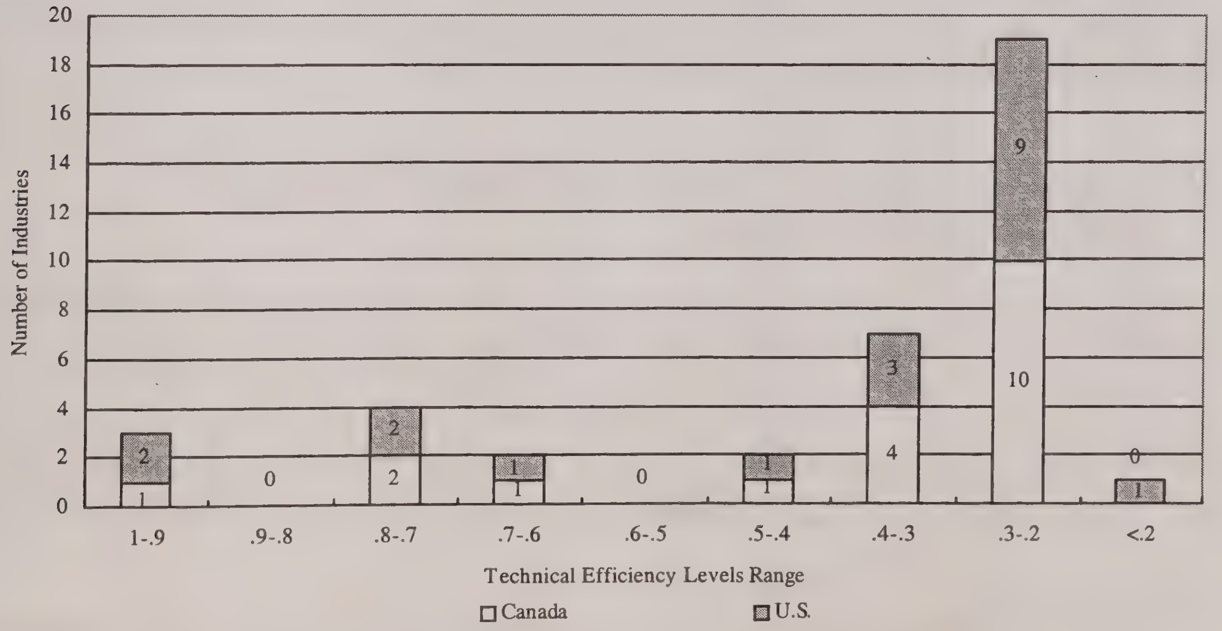
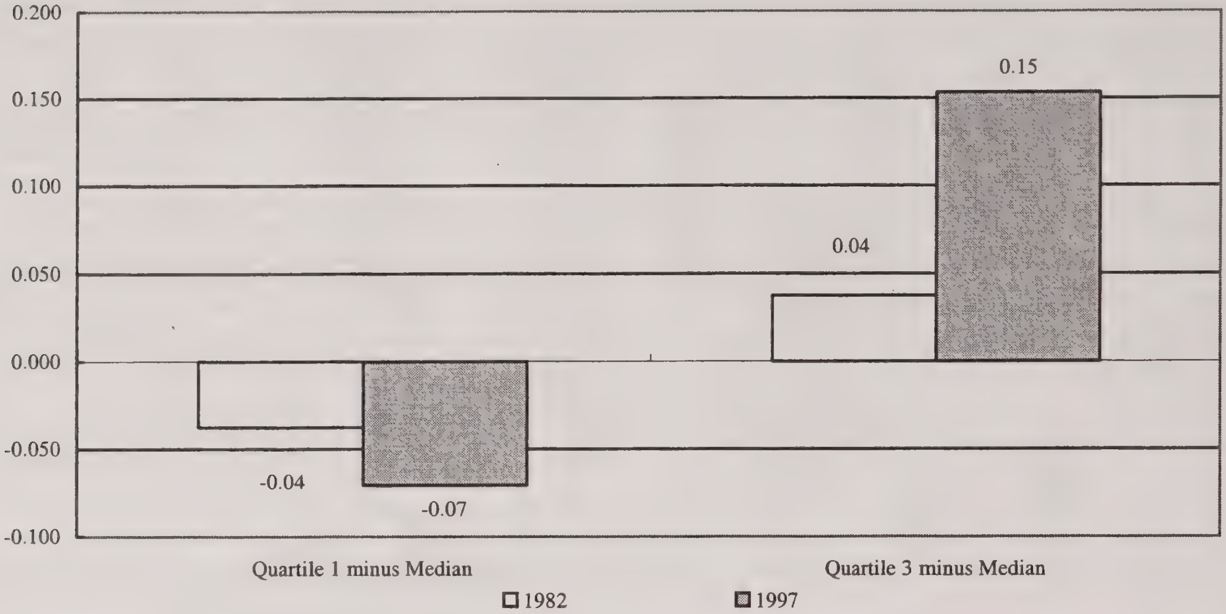


Figure 6. Interquartiles of Technical Efficiency Levels: North American Manufacturing Sector



The fact that the median of the level of technical efficiency declined sharply between 1982 and 1997 does not tell us whether the efficient industries were getting even more efficient and/or the least efficient saw their efficiency worsening over the years. The examination of the differences between the quartiles helps to answer this question. Figure 6 shows that the difference between the top quartile and the median increased by 0.22 percentage points between 1982 and 1997, compared with 0.08 percentage points between the bottom quartile and the median for the same period. Over the 1982-1997 period, there was a greater tendency for the efficient industries to get even more efficient than there was for the inefficient to decline.[8]

V. Comparison between Frontier and Standard Approach to Productivity Measurement

The results that have been presented herein make use of a methodology that is similar but not identical to that generally employed in productivity analysis. We therefore compare the results obtained under the frontier approach to productivity measurement to those based on the standard growth accounting framework. The standard multifactor factor productivity measure is determined simply as a residual difference between the growth in output and the growth in labour and capital. Therefore, it encompasses the effect of all influences on the efficiency with which

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8 Using microdata for the Canadian manufacturing sector over the 1973-1997 period, Braun and Townsend (2002) reached the same conclusion regarding the decline in efficiency over time in the Canadian manufacturing sector. Their work builds on Baldwin's (1992) definition of industry efficiency, defined as labour productivity in the industry over labour productivity in the most productive plants.

factors of production are employed. By construction, it is not simply a measure of the rate of technological progress.

The multifactor productivity average growth rate estimates under the standard growth accounting approach and the Malmquist approach are presented in Table 5. For the whole manufacturing sector, both measures of productivity reflect a gap in favour of the U.S., albeit higher under the frontier approach compared to the growth-accounting approach. Similarly, the frontier approach shows a higher variation (measured by as a standard deviation) across industries than the growth accounting approach from one country to another 1.23% for the frontier approach vs. 1.12% for the growth-accounting approach for Canada; 1.52 vs. 1.06 for the U.S. But both approaches yield consistent results at the industry level as evidenced by a high rank correlation (0.73 for Canada and 0.82 for the U.S.). For both countries, the top three industries in terms of productivity performance are almost identical under both approaches. This is less so for the bottom three industries.

Table 5: Multifactor Productivity Growth, 1981-1997 (Average Annual Growth Rate in Percentage)

	Malmquist		Growth Accounting	
	Canada	**U.S.**	**Canada**	**U.S.**
Food and kindred products	0.7	-3.0	1.2	-2.0
Tobacco	2.1	-2.0	-1.7	-4.7
Textile mill products	0.9	1.2	1.2	1.1
Apparel and related products	0.8	1.6	0.2	1.7
Lumber and wood products	-0.5	4.1	1.4	3.9
Furniture and fixtures	0.1	1.3	3.6	3.2
Paper and allied products	2.0	-1.5	1.4	0.1
Printing and publishing	-2.6	-0.8	-0.1	2.5
Chemical and allied products	2.9	-0.4	3.7	0.8
Petroleum refining	7.5	7.9	0.8	6.5
Rubber and misc. plastic products	1.9	-2.2	5.3	0.7
Leather and leather products	0.3	6.2	-4.0	1.0
Stone, clay, glass and concrete	2.5	2.4	1.1	2.1
Primary metals	5.5	1.0	5.1	-0.9
Fabricated metal	0.3	4.9	2.1	5.6
Industrial and commercial machinery and computer equipment	8.7	9.5	5.3	9.8
Electronic and other electrical equipment except computers	2.5	2.5	1.5	2.7
Transportation equipment	1.9	-0.9	4.5	0.2
Instruments and miscellaneous manufacturing	1.6	3.0	4.0	3.2
Manufacturing Sector	**2.0**	**2.7**	**2.7**	**3.0**

Important quantitative differences exist in some industries such as tobacco, and industrial and commercial machinery and computer equipment in Canada (leather and leather products and textile mill products for the U.S.). In all these industries, the Malmquist index produces a higher measure of productivity performance than the growth accounting approach and vice versa for furniture and fixture and transportation equipment (rubber and miscellaneous plastic products and furniture and fixtures for the U.S.).

VI. Conclusion

This paper uses the Malmquist index to measure multifactor productivity growth and decomposes it into an efficiency change and a technical change component. Both the Malmquist productivity index and the growth accounting approach provide similar results insofar as the Canada-U.S. productivity gap is concerned. However, the Malmquist index provides extra insight as it traces Canada's efficiency deterioration as the source of the gap not only for the business sector level but also for its constituent manufacturing and non-manufacturing sectors.

The second major result reached by this paper is the dramatic shift in the distribution of technical efficiency within the North-American manufacturing sector. The median efficiency dropped from 0.86 in 1982 to 0.68 in 1988 and to 0.40 in 1997. Similarly, all of the 38 manufacturing industries displayed an efficiency level above 0.70 in 1982, compared to only 17 in 1988, and only 7 in 1997. Out of these 17 industries in 1988, only 6 were Canadian (35%), compared to 3 out of 7 in 1997 (43%).

In light of these findings, we conclude that recent technical change has had differential effects across industries. In a sense, this is not a new conclusion. It is well known that productivity growth over the last two decades has been highest in the two industries that are at the heart of the micro-chip revolution. This paper simply quantifies the effect of this difference. What will become critical to overall progress is the extent to which the lagging industries begin to catch up as they incorporate the new information and communication technologies into their production process.

While these findings address the question that we posed at the beginning of the paper as to the causes of the increase in the productivity gap between Canada and the United States, they are only suggestive. In drawing conclusions, readers should take into account several caveats that are outlined below.

The first is the issue of the precision of measurement inherent in the Malmquist index and other productivity measures. We have emphasized (see Baldwin and Harchaoui, 2001) that productivity estimates are only point estimates that should be accompanied by a confidence interval. The confidence interval is required because data that are used for the calculation are subject to uncertainty. And some of the data are subject to revisions.

We argue that it is not easy to define the confidence interval that should be used for multifactor productivity estimates; but as a guide, we suggest that it could range from 0.2 to 0.4 percentage points. Many of the differences between Canada and the United States reported in this paper fall within these ranges or close to them. Therefore, the reader should treat the results presented herein as indicative of possibilities that need to be investigated with alternate datasets and alternate methodologies. Replication is required before strong conclusions can be drawn.

A second issue that needs to be addressed forthrightly is the very notion of inefficiency. In this paper, we postulate that firms or industries can be off the production frontier and that some of the increase in productivity that is normally measured arises from moving production toward the frontier.

The reader should recognize that not all economists accept the notion that some firms in an industry can be inefficient. And those who do may not be comfortable with the notion that an industry can be defined as inefficient based on the input/output combinations that exist in other industries. It is all too easy to go from the argument that petroleum plants cannot produce steel to the argument that production technology across industries is so different that one industry should not try to emulate the other in terms of how it transforms labour and capital into outputs.

While we accept this concern, we believe the type of exercise presented herein is useful to those who compare the ability of different economies to move their resources from less productive to more productive uses. Many observers have noted that one of the reasons that the American economy has been more productive than the Canadian is that the United States has expanded its information technology sector faster than Canada has. That observation and the associated concern essentially revolve around the belief that an economy's ability to take advantage of new industries is as important as its ability to produce what it already produces in the most efficient fashion.

There is another related reason that the frontier procedure that is used here yields useful results even in the face of differences in industrial structure. The procedure used here relies on measuring change. We are interested in asking whether the factors that influence efficiency are changing more or less quickly across countries. It is interesting to ask whether changes associated with the information technology revolution are moving industries forward at different paces. Removing the effect of industrial structure would be to ignore the fact that industrial revolutions affect industries differently. And the progress that is made by a country depends on its ability to reallocate resources to their most productive uses.

Appendix: The Malmquist Index

This appendix presents in more technical detail the index used in this paper to measure multifactor productivity growth. The index is defined in terms of output distance functions. These functions measure the ray distance between a given output vector and maximal potential output. This maximal output belongs to the boundary of the reference or frontier technology. We begin by explaining how the frontier is constructed from data.

We illustrate this approach using two sectors $i = 1,2$ at each time period $t = 1,2,...,T$ that use $x_i^t = \left(x_{K,i}^t, x_{L,i}^t \right) \in R_+$ inputs to produce a single output $y_i^t \in R_+$. From a pair of observations in each time period an overall sector of industry production technology is constructed for each time period. Rather than specifying and estimating a specific production function we choose to construct the technologies non-parametrically using activity analysis. This technique is also known as Data Envelopment Analysis (see Charnes *et al.* (1978)).

For a given period t, and given the observations for each of the two sectors $(x_{K,1}^t, x_{L,1}^t, y_1^t)$ and $(x_{K,2}^t, x_{L,2}^t, y_2^t)$, the frontier technology for period t is constructed as

$$S_{CRS}^t = \left\{ \left(x^t, y^t \right) : z_1^t y_1^t + z_2^t y_2^t \geq y^t, z_1^t x_{K,1}^t + z_2^t x_{K,2}^t \leq x_K^t, z_1^t x_{L,1}^t + z_2^t x_{L,2}^t \leq x_L^t, z_1^t, z_2^t \geq 0 \right\}. \qquad \text{(A.1)}$$

This formulation admits constant returns to scale (CRS) and free disposability of inputs and output. Output levels may be less than or equal to linear combinations of observed output; that is, output is freely disposable. Input levels may be greater or equal to linear combinations of observed input; that is, producers may freely dispose of inputs as well. The technology, and consequently the associated distance functions, are independent of measurement units and, although CRS is imposed in each period, each period is allowed to have a completely different CRS technology.

The intensity variables z_1^t and z_2^t indicate at what intensity a particular activity may be employed in the optimal production. In the CRS technology they are only required to be non-negative allowing the technology to form a cone of the data. If we add the constraint that restrict z_1^t and z_2^t to sum to one, the technology that would result is a convex combination of observed inputs and outputs, i.e. a variable returns to scale technology (VRS).

The output distance function for period t may be defined as (see Shephard (1970) or Färe (1988) for details):

$$\begin{aligned} D_{o,CRS}^t \left(x_i^t, y_i^t \right) &= \min \left\{ \theta : \left(x_i^t, \frac{y_i^t}{\theta} \right) \in S_{CRS}^t \right\} \\ &= \left[\max \left\{ \theta : \left(x_i^t, \theta y_i^t \right) \in S_{CRS}^t \right\} \right]^{-1} \qquad \text{(A.2)} \\ &= \left[F_o^t \left(x_i^t, y_i^t \right) \right]^{-1}. \end{aligned}$$

In (A.2), $F_o^t(\cdot)$ denotes the Farrell (1957) output-oriented measure of technical efficiency. Thus (A.2) shows that the distance function and the Farrell technical efficiency measure are reciprocals. This fact is important, since the productivity index is decomposed into two components: one measuring efficiency change and another measuring technical change. This index is known as the Malmquist index. It was introduced as a theoretical index by Caves, Christensen and Diewert (1982) (CCD), who named it the (output-based) Malmquist productivity index after Sten Malmquist who had earlier shown how to construct quantity indexes as ratios of distance functions (see Malmquist (1953)).

Following Färe *et al.* (1994), the Malmquist productivity change index is defined as:

$$M_o(x_i^{t+1}, y_i^{t+1}, x_i^t, y_i^t) = \left[\frac{D_{o,CRS}^t(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^t(x_i^t, y_i^t)} \cdot \frac{D_{o,CRS}^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^{t+1}(x_i^t, y_i^t)} \right]^{\frac{1}{2}}. \qquad (A.3)$$

This index is the geometric mean of two Malmquist productivity indexes as defined by Caves *et al.* (1982) (CCD), namely:

$$M_{CCD}^t = \frac{D_{o,CRS}^t(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^t(x_i^t, y_i^t)} \qquad (A.4)$$

and

$$M_{CCD}^{t+1} = \frac{D_{o,CRS}^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^{t+1}(x_i^t, y_i^t)}. \qquad (A.5)$$

An important feature of the Färe *et al.* (1994) version of the Malmquist index (A.3) is that it can be decomposed into two independent components, that is: efficiency change $\left(ECH_i^t\right)$ and technical change (TCH):

$$ECH_i^t = \frac{D_{o,CRS}^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^t(x_i^t, y_i^t)} \qquad (A.6)$$

$$TCH_i^t = \left[\frac{D_{o,CRS}^t(x_i^{t+1}, y_i^{t+1})}{D_{o,CRS}^{t+1}(x_i^{t+1}, y_i^{t+1})} \cdot \frac{D_{o,CRS}^t(x_i^t, y_i^t)}{D_{o,CRS}^{t+1}(x_i^t, y_i^t)} \right]^{\frac{1}{2}}. \qquad (A.7)$$

Note that (A.6) is equivalent to the ratio of Farrell technical efficiency in period t divided by Farrell technical efficiency in period $t+1$, whereas (A.7) is the geometric mean of the shift in technology as observed at the input level x^{t+1} and the shift in technology evaluated at x^t. Thus (A.3) can be written as:

$$M_o(i,t,t+1) = MALM_i^t = ECH_i^t \times TCH_i^t \qquad (A.8)$$

and for each industry i, time paths of productivity, efficiency and technical change can be calculated.

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